Appendix A to FAR 99-39

ENERGY INNOVATIONS SMALL GRANT (EISG) PROGRAM

EISG FINAL REPORT

HIGH-EFFICIENCY SINGLE-PHASE AIR CONDITIONER

EISG AWARDEE
Dr. OTTO J. M. SMITH
612 Euclid Avenue
Berkeley, CA 94708-1332 - USA
Phone: 1-(510)525-9126.
Email: <ojmsmith@earthlink.net>
Web Site http://www.home.earthlink.net/~ojmsmith

AUTHOR
Otto J. M. Smith, Principal Investigator

Grant #: 51542A/99-39
Grant Funding: $75,000.00
Term: August 15, 2000 - February 15, 2002.
PIER Subject Area: Building End-Use Efficiency

Legal Notice

Inquires related to this final report should be directed to the Awardee Dr. Otto J. M. Smith, (see cover page contact information) or the EISG Program Administrator at (619)594-1049 or email <eisgp@energy.state.ca.us>

Table of Contents

List of Tables

List of Figures

Abstract

The purpose of this project was to demonstrate that residential air-conditioners would have higher efficiencies when the compressors had and used readily-available three-phase motors instead of the conventional lower-efficiency single-phase motors. To connect the high-efficiency three-winding motors to the 2-wire single-phase supply, a Phase-Able™ Enabler™ circuit was used. An Enabler™ is a circuit of two or more capacitors which enables a three-winding motor to be connected to a 2-wire single-phase electrical supply, with the motor performance superior to that which the motor designer intended using a three-phase supply. These circuits and the Free-Wheeling Flux principal are described in the literature in many of the references listed herein.

The objective was to demonstrate significant efficiency improvements and electricity cost savings using the available industry cost-effective and competitive products, without additional research or additional factory facilities.

The outcomes were more beneficial than expected. A 48,000 BTU/Hour air-conditioning compressor had an EER (Energy Efficiency Ratio) of 11.95 BTU/(Watt-Hour), using the Enabler™ to connect it to the 230-volt single-phase supply. This was 11.74% higher than the same compressor with the single-phase motor which the factory made and sold to the public. A change to this new unit sold would save the consumer 11.7% of his electricity cost.

Two compressors were each tested with three conditions:

1. Three-phase supply to a three-winding motor.
2. Single-phase supply through an Enabler™ to the three-winding motor.
3. The same compressor with the conventional single-phase motor as sold almost universally in the United States for residences.

The larger unit was representative of the industry and the improvement was a savings of twelve percent of the electricity cost. The average savings for the industry with many different sizes of units could be possibly 10% of the electricity cost.

This means that the power companies can import less gas and oil energy to supply these new air conditioners, compared to the amount they would have needed to buy to supply the same air conditioners with the conventional single-phase motors.

There were several Enabler™ operating benefits**:** higher efficiency, less line voltage “sag” , better power quality with higher power-factor currents, and better winding current balances.

The conclusion of the author is that nearly all new single-phase air conditioners should be required or encouraged to use high-efficiency three-winding motors and be required to achieve correspondingly higher Energy Efficiency Ratios (EER). Ten percent increases in EER are appropriate in the California Energy Commission Appliance Efficiency Regulations for Room air conditioners and heat pumps, and for all Central air conditioners.

Key words for computer searches: High-efficiency air conditioners, Phase-Able Enabler controls, Semi-Hex Enabler controls, Single-Phase to Three-Phase controls, Energy Efficiency Ratios,

Hermetically-sealed compressors, Semi-Hermetically-sealed compressors, Power System overloads due to air conditioners.

Executive Summary

1. Introduction

Electric power system overloads often occur in a summer afternoon when many residential single-phase air conditioners are operating. Power companies bring on-line their most expensive, or least reliable, or oldest generators to minimize the probability of system collapse or a black-out. The cost to the power company and to society to supply these air conditioners at the peak load time is high, and could be higher than the rate which the customer is paying. Both the residential customers and the power companies deserve much higher efficiency air conditioners than are now available from the major suppliers.

The constraint is that most residences and perhaps 40% of all rural areas have only single-phase power, and it is uneconomic to change these distribution and wiring systems. The compressors are well designed, but the low efficiency single-phase motors on the compressor shafts are an obsolete design, and could be improved.

Enabler™ systems can operate high-efficiency three-phase induction motors from single-phase supplies with superior performances. Enabler™ systems can operate large three-phase induction motors from single-phase supplies, with power ratings many times larger than any single-phase motor.

The need is for all new air conditioners to have Enabler™ controls on high-efficiency three-winding motors on the compressors, yielding higher EER than presently sold.

2. Project Objectives

The objective was to prove that this need for high EER could be satisfied. We planned to measure two compressors, each with two different motors. Precise measurements of the thermodynamic compressor performance requires a very large installation of the type used to certify thermodynamic values for governmental agencies. We chose Intertek Testing Service, (ITS) with Corporate Headquarters at 25 Savile Row, London, England W1X 1AA, and with test facilities and laboratories at 3933 U.S. Route 11, Cortland, New York 13045.

We planned to measure the BTU/Hour pumped and the corresponding electrical watts required and the EER. We also planned to measure the winding voltage and current unbalances. We provided the Enabler™ controls.

3. Project Outcomes

All of the objectives were achieved for the two sizes tested. At ITS, each system operated on a single-phase supply through an Enabler™ to the three-winding motor with performance superior to that from a conventional three-phase supply, and performance superior to that using a conventional single-phase motor. The Model 48T was representative of the industry with a three-winding three-phase motor hermetically sealed with the compressor. Comparing the Enabler^{TM} control, Model 48E, to a conventional single-phase motor, Model 48S, the 48,000 BTU/Hour compressor had an EER (Energy Efficiency Ratio) of 12 BTU/(Watt-Hour), which was an EER of 11.7% higher than with the conventional single-phase motor.

With the Enabler^{TM} control , the winding current unbalance was only one percent, whereas with the three-phase supply, the same windings had a 7.4% current unbalance.

The single-phase input to the Enabler^{TM} control had a power factor of 90.8% LEADING, whereas the three-phase input to the windings had current with a power factor of 75.2% lagging. In every respect, the compressor performance with the Enabler^{TM} control was superior to that with the conventional three-phase supply for which the motor was designed.

The measured improvement was a savings of twelve percent of the electricity cost for the larger unit, Model 48E, which was representative of the industry products. The average savings for many styles and many sizes might be between 8% and 10% of the electricity cost. This means that the power companies can import less energy to supply these new air conditioners, compared to the imported energy amount they would have needed to buy to supply the same air conditioners with the old conventional "obsolete" single-phase motors.

Comparing the Enabler^{TM} control to a conventional single-phase motor, the Model 42E with a 42,000 BTU/HOUR compressor had an EER (energy efficiency ratio) of 11.3 BTU/(Watt-Hour) which was an EER of 4.% higher than with the conventional single-phase motor Model 42S.
With the Enabler^{TM} control, the winding current unbalance of Model 42E was reduced to 3.2%, whereas with the three-phase supply, the same windings had a 13.8% current unbalance. The single-phase input to the Enabler^{TM} control had a power factor of 88.3% LEADING, whereas the current in the three-phase windings had a power factor of 77.0% lagging. In every respect, the Enabler^{TM} control was superior to the performance with the conventional three-phase supply for which the motor was designed.

The Enabler^{TM} control made a factor of four improvement in the winding current unbalance of Model 42E compared to Model 42T. The 13.8% current unbalance for the Model 42T above might have been due to a factory mistake in the winding, and this motor should not have been approved for sale. If this motor had been correctly wound, the current unbalance might have been significantly less, more like a few percent, and the EER would probably have been significantly higher, more like the EER of 12 for the larger Model 48T unit.

The Enabler^{TM} is a current **injector ,** specifically designed to achieve better current balance in the windings, and a corresponding higher efficiency on single-phase than the motor efficiency when running from a three-phase supply as the factory intended. The Enabler^{TM} is not a phase converter.

4. Conclusions

The savings of 12 percent in the electricity cost for the 48,000 BTU/HOUR unit using the Enabler^{TM} control can probably be realized by most manufacturers of air conditioners of this size. Smaller units with adequate quality control could probably realize 8% or 10% electricity savings.

Industry-wide, with units both larger and smaller than these that were tested, Enabler™ controls on three-winding (three-phase) motors could be expected to average a ten percent savings in electricity cost by using a slight modification of the present designs of the three-winding (three-phase) motors and the present designs of the Enablers™. This could use minimal research laboratory facilities or activity, and no new or different manufacturing shops or equipment.

5. Recommendations

All air conditioners should have EER or Energy Guides published and attached to the units. Minimum EER values (like 8) could be required, EER values of 10 could be realized, and higher EER values (like 12) could be subsidized or required by agencies devoted to energy efficiency.

Financial incentives might accelerate the commercialization of these units. The conclusion of the author is that nearly all new air conditioners should be required or subsidized to achieve higher EER by the use of high-efficiency three-winding motors with Enablers.

Here is an opportunity for manufacturers to sell units on the basis of life-time costs (electricity plus initial cost) and not push initial cost only for customer decisions. On life-time cost basis, the energy savings would be divided several ways, with customers receiving lower electricity costs, manufacturers benefiting by charging more initial price because the customers will be paying a higher initial price in anticipation of better electricity costs, and the power companies benefiting due to higher distribution efficiency, better current power-factor in the distribution lines, lower spikes due to starting currents, and lower fuel costs per BTU of cooling achieved.

In sequence, first, a manufacturer should be persuaded to market an entire line of single-phase air conditioners, all sizes, all using Enabler™ controls on three-winding motors in the refrigerant compressors. This Enabler™-controlled compressor is inserted instead of the single-phase compressor into a single-phase system. The single-phase system is electrically connected to the single-phase supply as usual.

Secondly, many factory representatives should be invited to confer with the CEC engineers to jointly set new energy guides and regulations. Thirdly, the CEC can write new regulations. Ten percent increases in EER are appropriate in the California Energy Commission Appliance Efficiency Regulations for Room air conditioners and heat pumps, and for all Central air conditioners.

6. Public Benefits to California.

With Enabler™ controls on three-winding air conditioners, the primary benefit is high efficiency and reduced electricity cost to the residential customers and other customers with only single-phase supplies. Several secondary benefits to the electrical power companies are

(1) reduced peak MW demand at the summer peak,
(2) improved system stability,
(3) lower electricity and energy costs at the summer peak,
(4) higher power quality due to leading power-factor currents,
(5) higher distribution efficiency due to leading power-factor currents,

(6) higher power quality due to less starting-current demand on the distribution transformers and lower current spikes, and
(7) lower harmonic and pulse distortions of the electrical supply.

The general public, exclusive of the air-conditioner customers, benefit from
(1) reduced probability of rolling black-outs,
(2) reduced voltage “sag” or less voltage reduction due to air-conditioning loads,
(3) better power quality, and
(4) rates reflecting the increased efficiency of the power-company distribution system.

1. Introduction

Almost all residences in the U.S.A. are electrically wired with single-phase electrical power, usually 230 or 240 volts, with the center-tap of the supply grounded. This is also the electrical supply for many motels and small commercial buildings. Large rural areas in the U.S. have only single-phase electrical power supplied from the power company.

Single-phase motors in the one-HP (one horsepower) up to ten-HP sizes are less efficient than the equivalent quality three-phase motors. A Baldor 15-HP TEFC 4-pole single-phase motor, winding 09Y26, has a full-load efficiency of only 82.5%, with losses of 21.2%. See reference (14) to Baldor Catalog 502. A 15-HP TEFC 4-pole three-phase motor, winding 09W980, has the better full-load efficiency of 92.4% with losses of only 8.2%. The electricity cost for the single-phase motor would be 12% higher than for this 3-phase motor. A different 15-HP TEFC 4-pole three-phase motor, winding 07W269, has a full-load efficiency of 90.2%, with losses of 10.9%. Considering this conventional-efficiency three-phase motor, compared to the single-phase motor, the electricity cost for the single-phase motor would be 9% higher than for this latter general-purpose 3-phase motor.

These considerations motivated the invention of a Phase-Able™ Enabler™, a circuit which enables any high-efficiency three-phase motor to be connected to a single-phase supply. Installations of this type have been successful. See references (8) Smith and Shock, 1999; (5) Smith 1997, (6) Smith 1998, and (7) Smith 1999. This invention received an R&D100 Award as one of the 100 Most Technologically Significant New Products of the Year 1999.

Initial costs are also very important. Single-phase motors in the one-HP to ten-HP sizes are more expensive than the equivalent quality general-purpose three-phase motors.

Air conditioners for residences have single-phase motors mounted on the shaft of the refrigerant compressor inside of an hermetically-sealed compartment. The same compressors with three-phase motors are also readily available.

It was assumed that these single-phase motors being used in the air conditioners had lower efficiencies than an equivalent three-phase motor for the same compressor.

It was assumed that an Enabler™ with the higher-efficiency three-phase motor could connect the unit to a single-phase supply, thereby saving substantial energy compared to the old “obsolete” single-phase motor system. It was desired and expected that the Enabler™ air conditioners would have higher efficiency, better current balance in the windings, and lower starting currents.

The air-conditioning loads in the U.S. and California are substantial, and this new invention could save significant dollars for new customers, and could save significant MW loads for the power companies.

Electric power system overloads often occur on a summer afternoon when many residential single-phase air conditioners are operating. Power companies bring on-line their most expensive, or least reliable, or oldest generators to minimize the probability of system collapse or a black-out.

The cost to the power company and to society at this time to supply these air conditioners with expensive power is high, and the actual cost could be higher than the rate which the customer is paying.

2. Project Objectives

The goals of this project were to prove the assumptions in the Introduction, to perform research on commercial products, to make Enablers™, and to make proof-of-feasibility tests. These goals can be summarized by these tests and data processing:

2.1 Single-phase-motor on compressor efficiency tests (EER, Energy Efficiency Ratio tests).

2.2 Three-phase-motor on compressor efficiency tests (EER, Energy Efficiency Ratio tests).

2.3 Design and construction of Enabler™ for the three-phase-motor on a compressor efficiency test from single-phase supply.

2.4 Compressor efficiency tests (EER, Energy Efficiency Ratio tests) on Enabler™ from single-phase supply to three-phase-motor.

2.5 Circuit for starting the three-phase motors supplied from the single-phase electrical supply.

The goals were to show that the available three-phase motor and compressor systems would (1) operate satisfactorily with an Enabler™ from a single-phase supply,

(2) that the new system would have a higher efficiency (EER) than the same compressor with a single-phase motor, and

(3) that the new system would even be superior to the available compressor with the three-phase motor.

(4) The tests would show high efficiency, better current balance in the windings, and lower starting current.

These are the goals in the Stage 3 of the Stages And Gates Process of the Energy Innovations Small Grant Program, specifically testing of critical components and the full system at laboratory or basic research phase resulting in a proof-of-feasibility for Gate 3.

3. Project Approach

The major components that were purchased were

(1) Model 48T, a 48,000 BTU/Hour air-conditioning compressor with a 230-volt three-phase motor.

(2) Model 48S, the same 48T 48,000 BTU/Hour air-conditioning compressor with a 230-volt single-phase motor.

(3) Model 42T, a 42,000 BTU/Hour air-conditioning compressor with a 230-volt three-phase motor.

(4) Model 42S, the same 42T 42,000 BTU/Hour air-conditioning compressor with a 230-volt single-phase motor.

Enabler™ controls were designed and constructed for
Model 48E using the compressor of Model 48T, and for
Model 42E using the compressor of Model 42T.

All components and controls were sent to Intertek Testing Services, (ETL SEMKO), 3933 US Route 11, Cortland, NY 13045.   Dr. Smith went to the company testing facilities and supervised the electrical measurements. Donald James was the Operations Supervisor of ITS and supervised the thermodynamic tests and measurements and their data processing.

For each test, thermodynamic equilibrium was established for the ASHRAE-T standard conditions specified in Appendix I, copied from reference (2) ASHRAE Standard 23-1993. Four measurements were made over a 30-minute time interval, and the averages were processed.

Secondly, thermodynamic equilibrium was established for the ARI standard conditions specified in Appendix I, copied from reference (1) ANSI/ARI Standard 500-90. Four additional measurements were made over a 30-minute time interval, and the averages were processed.

There were twelve complete tests made, with the pairs listed below:

(1) EER of Model 48T with a 230-volt three-phase electrical supply, both ASHRAE and ARI.
(2) EER of Model 48E with an Enabler™ and a 230-volt single-phase supply, both ASHRAE and ARI.
(3) EER of Model 48S with a 230-volt single-phase electrical supply, both ASHRAE and ARI.
(4) EER of Model 42T with a 230-volt three-phase electrical supply, both ASHRAE and ARI.
(5) EER of Model 42E with an Enabler™ and a 230-volt single-phase supply, both ASHRAE and ARI.
(6) EER of Model 42S with a 230-volt single-phase electrical supply, both ASHRAE and ARI.

In addition to EER, measurements were made of currents and current unbalance, voltages and voltage unbalance, and wattmeter readings adequate for calibrations.

4. Project Outcomes

Efficiency. Our major attention is to high efficiency, represented by high EER, and to saving energy. TABLE 4.1, **EER SUMMARY MEASURES EFFICIENCY**, shows the average EER of both ASHRAE and ARI conditions. With attention to the 48,000 Btu/Hour compressor, using the three-phase motor as provided on the Model 48E, the EER of 11.95 with this three-phase motor and Enabler™ will save the customer 12% of his electricity cost, compared to using the single-phase motor on the same compressor, Model 48S, with an EER of only 10.694. This is representative of the industry, and similar performance can be expected for many makes, models, styles and sizes.

With attention to the 42,000 Btu/Hour compressor, using the three-phase motor as provided on the Model 42E, the EER of 11.294 with this three-phase motor and Enabler™ will save the customer 4% of his electricity cost, compared to using the single-phase motor on the same compressor, Model 42S, with EER of only 10.865. Model 42T, the three-phase unit, was faulty, with unbalanced currents in the windings, possibly due to an error in manufacturing the winding of the motor.

The average EER of both systems in Table 4.1 was 11.6 for the Enabler™ systems and 10.8 for the conventional single-phase winding. From this average, a customer would save at least 7.8% of his electricity bill by using an Enabler™ system instead of using the present conventional single-phase system with a single-phase motor.

This table 4.1 proves goals (1) and (2) in the paragraph 2. Project Objectives.

TABLE 4.2 lists the **FULL-LOAD THREE-PHASE MEASUREMENTS**. The ARI and ASHRAE-T tests are very similar. The average of these is a good measure of what the industry can expect for different operating conditions. The use of the Enabler™ for Model 48E increased the BTU/Hour pumped by the compressor by six-tenths of one percent, but used 4.7 percent more electrical power input. The net result was a decrease in EER of four percent.

The use of the Enabler™ for Model 42E increased the BTU/Hour pumped by the compressor by 0.43 percent, and used 4 percent less electrical power input. The net result was an increase in EER of 4.4 percent.

It was not this project goal to improve on the existing three-phase designs. We documented instead what is available, its characteristics, and the improvement for new single-phase customers to not buy single-phase units, but instead to buy three-phase units with Enabler™ controls.

TABLE 4.3, **UNBALANCED CURRENTS IN WINDINGS**, shows both the performance on a three-phase supply, as the factory expected, and the performance of the Enabler^{TM} from a single-phase supply.

The 48T compressor, on three-phase as designed, had an average winding current of 13.41 amperes, and the current unbalance was 7.4%. It would be desirable to have a better current balance. This unbalance, however, displayed an important advantage of the Enabler^{TM}. The Enabler^{TM} **injects** a current into winding W3-W6, and this injected current almost balances the winding currents. This improved balance increases the single-phase efficiency to be higher than the three-phase efficiency expected by the factory. The same 48E compressor, with an Enabler^{TM} and a single-phase supply, had an average current of 13.43 amperes, and a current unbalance reduced to only 1.05 %, which is **SEVEN** times better. This was quite satisfactory. The Enabler^{TM} automatically compensates for a poor factory quality control or a design without attention to the current unbalance. To compensate for the current unbalance, the cost was an increase in voltage unbalance of only one percent, which is not important and is quite reasonable. The Enabler^{TM} is **NOT** a phase converter, which would apply a voltage to winding W3-W6, and can not balance the currents. This project is not aimed at better motor designs, but only at a better utilization of the existing designs.

Faulty winding.

The 42T compressor, on three-phase as designed, had an average winding current of 12.46 amperes, and the winding current and the power-line current unbalances were 13.8%, which is terrible. A motor with this terrible current unbalance should never pass the quality control at the factory, and should not be sold to the public. This poor quality is displayed in Table 4.1 with an EER of only 10.82, far out of line with what the industry should expect. The EER should have been 12.4, like the Model 48T.

The same 42E compressor, with an Enabler^{TM} and a single-phase supply, had a current unbalance of only 3.22% which is four times better. This is a desirable improvement, resulting in more uniform winding heating, and less noise and vibration. This improvement, created by the Enabler^{TM} injected currents, is reflected in Table 4.1 by an 11.29 EER. Here the Enabler^{TM} has salvaged a bad air-conditioner compressor and made it useful. Phase converters can not do this and are inferior in performance to the Enabler^{TM} .

Table 4.3 proves goals (3) and the better current balance in goal (4). Starting currents for goal (4) were not measured.

Table 4.4, **FULL-LOAD THREE-PHASE MEASUREMENTS**, are the actual winding full-load characteristics. These are the direct tests which can be compared to the factory specifications, which should be the same. To design the Enablers^{TM}, the winding current and power-factor provided by the factory in Table 4.5 were used. The values that should have been used are those in Table 4.4. For the Model 48T, the current was 13.4 amperes at 72.45% power-factor. For the Model 42T, the current was 12.46 amperes at 77.92% power-factor.

Table 4.5, **FULL-LOAD THREE-PHASE FACTORY EXPECTED VALUES**, are the winding full-load characteristics as provided by the factory. These were the values used by Dr. Smith to design the Enablers™.

The 48T expected current was 13.6 amperes, 1.4% high, compared to the actual current of 13.4 amperes. The expected power-factor was 75.1%, 3.7% high, compared to the actual power-factor of 72.45%.

The expected full-load phasor current lag angle of the 48T was 41.32°, 2.25° low, compared to the actual lag angle of 43.57°.

These differences were responsible for the voltage on the motor winding not connected to the power supply being 1.6% high when operating with the Enabler™ control.

The 42T expected current was 11.6 amperes, 7.4% low, compared to the actual current of 12.5 amperes. The expected power-factor was 82.5%, 5.9% high, compared to the actual power-factor of 77.9%. The expected phasor lag angle was 34.42°, 4.39° low, compared to the actual lag angle of 38.81°. These differences were responsible for the voltage on the motor winding not connected to the power supply being 1.8% high when operating with the Enabler™ control.

The difference between the Enabler™ design based on the incorrect values in Table 4.5 and the correct values in Table 4.4, that should have been used, demonstrates the robustness of the Enabler™ control and its superior performance for large variations in parameters of either the motor or the Enabler™.

TABLE 4.6 lists the **FULL-LOAD ENABLER™ WINDING MEASUREMENTS**, which were used to calculate the EER. Model 48E pumped 48,416.82 BTU/Hour. The input was 4,052.02 watts. The EER of 48E was 48,416.82 / 4,052.02 = 11.95 BTU/(WATT-HOUR). Table 3.1 has this value in column two.

Model 42E pumped 42,010.62 BTU/Hour. The input was 3,719.75 watts. The EER of 42E was 42,010.62 / 3,719.75 = 11.294 BTU/(WATT-HOUR). Table 3.1 has this value in column two.

When operating from Enabler™ on single-phase, the three motor windings had the average voltages listed in Table 4.6. These show that the average voltages were 232.5 and 232.7 volts respectively for the two models terminal-to-terminal. These higher voltages were due to the Enabler™ design based on the values in Table 4.5, instead of the correct values listed in Table 4.4.

The higher voltages from Table 4.6 also appear in Table 4.3, in the section for Enabler™ connection to single-phase power. Note that these higher voltages also correspond to lower current unbalance.

The power-factors listed in Table 4.6 also correspond to the three windings operating nearer balanced currents, and are more important for commercial designs than the values listed in Table 4.4, which were measured with the large unbalanced winding currents.

TABLE 4.7 lists the **FULL-LOAD ENABLER™ SINGLE-PHASE INPUT MEASUREMENTS**. The Power Company Single-Phase line sees an improved power quality.

For the Model 48E, the single-phase line power factor was 90.8% leading, a large improvement over the three-phase motor winding power factor of 75% lagging. For the Model 42E, the single-phase line power factor was 88.3% leading, again a large improvement over the three-phase motor winding power factor of 76.7% lagging. These high leading power-factors reduce or eliminate voltage sag. They also improve the power company distribution efficiency.

For the Model 48E, the single-phase line current was 1.44 times the three-phase line current. For the Model 42E, the single-phase line current was 1.52 times the three-phase line current. The single-phase line current must be larger than the three-phase line current, to deliver the same power.

The **FULL-LOAD ENABLER™ BALANCED WINDING VALUES FOR 230 VOLTS** are listed in Table 4.8. These values are calculated from Table 4.6, which has better winding balance than Table 4.4. The change is the voltage from 232.5 down to the rated voltage of 230 volts. Corresponding changes in current and power factor are given in the reference (14) Baldor Catalog 502, Figure 2, page A-4.

Table 4.4 should not be used for new designs, because of the large current unbalance, and instead, Table 4.8 should be used because it was derived from measurements with a better current balance. In Dr. Smith's experience, all previous Enabler™ systems had currents balanced to approximately one percent.

The **Semi-Hex™ Enabler™ winding connection** shown in Figure 4.1 can be used in commercial manufacturing of air conditioners for market sales.

The three windings have terminals W1 through W6. The first winding has terminals W1 and W4. The second winding has terminals W2 and W5. The third winding has terminals W3 and W6. The single-phase power line has terminals L1 and L2.

Line L1 is connected to Winding Terminal W1.

Winding Terminals W4 and W5 are connected together and to new terminal T45.

Winding Terminals W2 and W3 are connected together and to Line L2.

RUN CAPACITOR CONNECTIONS:

Capacitor C1 is connected between Line L1 and Winding Terminal W6.

Capacitor C2 is connected between Line L2 and new Winding Terminal T45.

Capacitor C3 is connected between Winding Terminal W6 and new Winding Terminal T45.

The electrical connections in Figure 4.1 are for a voltage phase sequence of W3-W2-W1. This phase sequence is common in agricultural applications, where the resulting CW rotation matches the water pump.

New Enabler™ controls will use the measured performances of the actual motors, not the factory expected values unless these are known to be correct. Table 4.8 should be used for the rated 230 volts. From the data in Table 4.8, new rated values for capacitors were calculated and listed in Table 4.9. These values are appropriate for these two specific compressors.

The current components in the run capacitors are:

$$(I30) = 2 \times (FLA) \sin(60^{o} - \Phi^{o}) \qquad 4.1$$

$$(I60) = 2 \times (FLA) \sin(\Phi^{o} - 30^{o}) \qquad 4.2$$

The capacitor values are computed as:

$$C1 = \{ (I30) / (377 \times 265.6) \} \times 10^{6} \quad \text{MFD} \qquad 4.3$$

$$C2 = \{ (I30) / (377 \times 132.8) \} \times 10^{6} \quad \text{MFD} \qquad 4.4$$

$$C3 = \{ (I60) / (377 \times 230.0) \} \times 10^{6} \quad \text{MFD} \qquad 4.5$$

The run-capacitor <u>leading</u> vars contributions are

VAR1 = (I30)(265.6) varc 4.6

VAR2 = (I30)(132.8) varc 4.7

VAR3 = (I60)(230.0) varc 4.8

The total run capacitor leading VARCS = VAR1 + VAR2 + VAR3. 4.9

The run capacitive vars from equation 4.9 for the 42T motor from Table 4.8 is

VARCS = = 4,297.8 vars leading 4.10

The motor full-load magnetic lagging varm is

VARM = (FLA) (230) (1.732) (sin Φ^{o}) = 3,083.9 varm. lagging 4.11

At full-load, the single-phase line receives the difference of

VARL = VARCS - VARM = 1,213.8 line vars leading. 4.12

The watts WL in Table 4.8 is 3,721.57 line watts.

The line volt-amperes VA = sqrt ($WL^2 + VARL^2$) = 3,914.50 4.13

The line power-factor PF = WL /VA = = 3,721.57 / 3,914.5 = 0.9507 4.14

The line current lead angle is acos (PF) = ΦL^{o} = 18.07^{o} 4.15

The single-phase line current is (VA) / 230 = 3,914.5 / 230 = 17.02 amps. 4.16

Table 4.9 shows the results of these calculations. Table 4.9 also shows separate calculations for Model 48T.

Table 4.9, **CAPACITOR MFD VALUES FOR SEMI-HEX™ ENABLER™ 4-TERMINAL CONNECTION TO 230 VOLTS**.

These values from equations 4.1 through 4.16 for compressors 48E and 42E with the SEMI-HEX™ ENABLER™ Connection are summarized in Table 4.9. These computational methods are given in the Smith and Shock reference (8), 1999, and in many of the other references, e.g., (10) Smith 1999.

Table 4.10, **FULL-LOAD COMPRESSOR OUTPUTS**, shows the performance of the Scroll Compressor alone. The use of the Enabler™ increases the output of the compressor, primarily due to increased shaft speed (reduced slip). This improvement is approximately one-half of one percent. This is another contribution to goal (3) in paragraph 2. Project Objectives.

Table 4.11, **COMPRESSOR COMPARISONS,** with values from Table 4.4, shows that the compressor on Model 48T delivered an average of 48,140.37 BTU/HOUR at the ARI and ASHRAE-T thermodynamic full load conditions with three-phase supplied to the hermetically-sealed motor. This same compressor with Model 48E circuit delivered 48,416.82 BTU/HOUR at the thermodynamic full load. The average of these is notated 48A and is 48,278.6 BTU/HOUR.

A different compressor from the same production line and intended to be identical to the above was installed in the Model 48S with a single-phase motor. This delivered only 46,771.75 BTU/HOUR at the ARI and ASHRAE-T conditions. This latter compressor and single-phase motor had an output of 96.88% of the output of the average of the former compressor with the three-phase motor. This means that the shaft of the single-phase motor is rotating at a slower speed than the shaft of the three-phase motor.

Assuming that the mass flow rate of the refrigerant is linearly proportional to the speed, and that the heat rate per unit of mass is also linearly proportional to the speed, and that the BTU/HOUR pumped is therefor proportional to the square of the speed, then the speed ratio is proportional to the square-root of the Q in BTU/HOUR. This factor yields a speed ratio in Table 4.11 of 0.9843. This means that the shaft of the single-phase induction motor is rotating at approximately 98.4% of the speed of the shaft of the three-phase induction motor. Stated differently, the slip of the single-phase induction motor is perhaps forty percent larger than the slip of the three-phase induction motor for the same torque and power. This is normal and is to be expected. These readings imply that the two compressors are practically identical in construction.

Table 4.12, **COMPONENT RETAIL PRICES, MODEL 48E.**

The price of the 48E compressor and controller today would be $428.00. Large production runs of the compressor can reduce the price by 20%. Large purchases of standard capacitors can possibly save 50% of the list prices. The expected future retail price of this system is $304.00.

The competition is the conventional single-phase low-efficiency system. This is a topic beyond the scope of this report, and should be addressed by a marketing expert. The conventional single-phase system price today is $300.51. That makes the high-efficiency system attractive. In the future, it is possible that reduced sales of these low-efficiency units could increase their cost by 20%, up to $360.00. In the future, the customer would be saving $60.00 per unit to buy the high-efficiency unit.

Figure 4.2, **PROPRIETARY CIRCUIT FOR AUGMENTED STARTING TORQUE** shows the cable connections from EC, FC, GC, and HC from Figure 4.1 to Figure 4.2. The Model 48E compressor did not start on the run capacitors alone. A starting contactor added extra electrolytic motor starting capacitors sufficient to make the starting current unity power factor. This minimizes starting current for full torque. This is design “overkill”, since all that would be commercially necessary would be a fraction of this starting capacitor volt-amperes-reactive (VARCS).

The run capacitors for this model 48E from equation 4.9 have 4,681.08 varcs leading. Assuming that the motor has locked-rotor current of 62.2 amperes at 52.65% power-factor and LRΦ of 58.23^o , the locked rotor magnetizing varm is 21,065.63 varm lagging. To make the power line see a unity power-factor on starting, the capacitors must contribute the entire 21,065.63 varcs. The run capacitors in Table 4.9 contribute only 4,681.08 varcs leading.

The electrolytic starting capacitors must contribute the additional 16,384.55 vars leading to bring the supply line to zero vars, unity power-factor, and minimum starting current. This is desirable for large installations, where a large starting current might be an important consideration for the power company. Unity-power-factor starting yields minimum line current for full accelerating torque.

To put this in perspective, 16,385 vars leading at 230 volts is approximately 71 quadrature amperes, which is 822 microfarads. The capacitances of electrolytic starting capacitors vary with voltage, temperature, and recent past history. The manufacturers give only broad ranges of possible values for their products. All of the previous designs of Dr. Smith used unity-power-factor starting with capacitors whose values were measured before installation. This is far more careful than is needed.

An additional study has shown the minimum starting capacitors required for the starting torque, in order to save initial costs.

PRACTICAL STARTING SYSTEM DESIGNS

The Model 48E compressor motor started turning and accelerated up to full speed in a fraction of a second with augmented starting torque from only 150 varcs in addition to the run capacitors. The starting capacitive varcs was approximately five percent additional to the run varc. Starting with full back pressure on the compressor used 600 varcs, approximately 20% of the run vars. This is an enormous margin of safety. Most air conditioners lock-out the starting to prevent a restart in five minutes.

The electrical circuit design in Figure 4.3 is what will be used in a practical retail production product. This has a voltage phase sequence of W1-W2-W3, which is opposite to that in Figure 4.1. With the capacitor values in Figure 4.5, this will restart immediately with high back pressure.

This is a satisfactory economic system, which is not unity-power-factor starting and is not minimum line starting current.

The Model 42E compressor with the Enabler™ circuit started rotating on the run capacitors alone. No augmented-torque starting circuit was needed. The assumed locked-rotor current was 49.1 amperes and locked-rotor power-factor was 50.7%. The motor locked-rotor magnetic vars was 16,859.7 varm lagging. These needed only the 4,297.8 varcs leading in equation 4.10 for starting torque on the shaft and for starting rotating.

FACTORY DESIGN FIGURES

Figure 4.3 shows a single-phase air conditioner containing a compressor with a single-phase motor. The usual connection of the single-phase motor shown at the top of the page is to terminals "C", (common), "R" , (run), and "S" , (start).

The lower circuit is the same single-phase air conditioner in which the single-phase compressor has been removed, and replaced by the three-phase compressor with terminals C, R, T45, and W6. The electrical cable from these terminals into the capacitor box has electrical leads HC, EC, GC, and FC respectively. Run capacitor C1 is connected between EC and FC. Run capacitor C3 is connected between FC and GC. Run capacitor C2 is connected between GC and HC. Start capacitor CS3 in series with the proprietary CS3 Start Circuit is connected between FC and GC, which is equivalent to connection in parallel with run capacitor C3.

This Figure 4.3 is how a product should be manufactured and sold.

Figure 4.4 is the same circuit diagram with the windings drawn in parallel with the voltage phasors across each. Many of the references have their circuits drawn in this manner. For the Model 48E, the run capacitor microfarad values are 87, 174, and 61 for capacitors C1, C2, and C3 respectively. The voltage phase sequence is W1-W2-W3.

Figure 4.5 shows the connections in the capacitor box of the cables EC, FC, and GC to the starting capacitor and its associated proprietary Start Circuit. Start capacitor CS3 of 75 microfarads (mfd) can be used as shown in Figure 4.3. Alternatively, start capacitor CS1 of 100 mfd can be used as shown in Figure 4.6. These values are much larger than needed for a marketed product. For normal starting, after an air conditioner has been off for five minutes, the start capacitor can be one-third or less than the value listed in Figure 4.5.

Figure 4.6 shows the same compressor as in Figure 4.3, with the starting capacitor being CS1 instead of CS3.

Figure 4.7 is a drawing with dimensions in millimeters of the four-terminal FUSITE bushing that would be used for the four-terminal three-phase motor connections of the Semi-Hex^{TM} circuit in Figure 4.4. Single-phase compressors today use 3-terminal FUSITE bushings. The bushing is resistance-welded into the wall of the hermetic chamber.

The new complete Enabler^{TM} compressor systems, ready to be installed into air conditioners, can be assembled by the same companies that now produce the compressors for Bristol, Carlyle, Goodman, Rheem, Lennox, Emerson-Copeland, GE Zoneline, Trane, Tecumseh, International Comfort Products and others.

5. Conclusions

5.1 The air conditioner compressor Model 48E with an Enabler^{TM} had an EER of 12. This was 11.7% better than the same compressor with a single-phase motor on the shaft, which had an EER of only 10.7. Industry-wide, we can probably achieve a 10% improvement in EER by using Enabler^{TM} controls on all three-winding (three-phase) motors on air conditioners to be connected to a single-phase source.

5.2 This air-conditioner compressor Model 48E with three-phase windings and energized directly from a three-phase source had the efficiency of BTU/(WATT-HOUR) of 12.4 EER. This is representative of the industry for this size. Many air conditioner manufacturers could probably duplicate this. Smaller units might have lower efficiency, so that the average for all three-winding (three-phase) units sold might have an EER near to 10. This is the industry constraint to which our designs can be adapted.

5.3 This improvement is applicable to single-phase air conditioners in residences, motels, small commercial buildings and rural communities with only single-phase power.

5.4 The energy savings of a program to use these Enabler^{TM}-controlled air conditioners will reduce the new electricity demand from California electrical suppliers, and will reduce the need for imported energy from Canada, from Mexico, and from the near East.

5.5 Improved power quality is another benefit to the power companies. The line current power-factor of these new air-conditioner loads is significantly improved, and this increases the distribution efficiency of the power companies.

5.6 The run capacitors diminish the harmonic distortion, also improving the power quality for the power companies.

5.7 The Enabler^{TM}-controlled motors had improved current balance, which contributed to improved motor efficiency, which in turn reduced shaft slip, increased shaft speed, and made the compressor deliver more BTU/Hour.

5.8 Most single-phase air conditioners in residences, motels, small commercial buildings and rural communities with only single-phase power should use air conditioners with three-phase motors and with Enabler^{TM} controls to save energy.
5.9 The test results of this program satisfy Gate 3 of Stage 3 of the Stages and Gates Program of the California Energy Commission for the Model 48E size, 48,000 BTU/Hour.   The original grant expected to cover testing of many different sizes. The smallest available size should now be tested to encompass the commercial range.

6. Recommendations

6.1 It is recommended that Energy Guides be measured and required for new air conditioners, and that higher EER and higher efficiencies be encouraged, subsidized, or mandated for California. 8% improvements in EER can be mandated, 10% improvements can be quickly achieved, and 12% improvements could be subsidized. These improvements can be readily realized with minimum modifications to the present designs of three-phase motors, and the inclusion of Enabler^{TM} controls with the three-phase motors in the single-phase systems.

6.2 It is recommended that the California Energy Commission start discussions with the major air-conditioner manufacturers to adopt industry Energy Guides and EER values for units to be operated from single-phase power consistent with present or achievable three-winding (three-phase) motor designs, with the goal of significantly improving the EER of these units for connection to residential, rural, small commercial and motel single-phase power.

6.3 It is recommended that the California Energy Commission provide assistance and funding for approaching the vice-presidents of marketing of large air conditioning companies, to encourage them to market complete lines of single-phase air conditioners of all sizes, utilizing their three-phase compressor systems with Enabler^{TM} controls in nearly all of their single-phase systems.

6.4 It is recommended that each factory assembling the motor and compressor have an assembly line quality control step (like most motor manufacturers) at which the impedances of the motor windings be automatically measured and stored in a computer, and unbalanced-impedance motors be rejected or flagged for special treatment.

7. Public Benefits to California

These technical feasibility tests confirmed the original expectation that these units would diminish the distribution and generation costs for electricity at the peak load times in the summer. They also diminish the probability of rolling blackouts. These are benefits for everyone, all power companies and all customers.
The cost benefits to the new air-conditioning customers are large.

The annual electricity usage in California (Year 2000) is 274,000 Giga-Watt-Hours (GWH). Space cooling in California uses 12,300 GWH. The annual growth rate is 11.5%. The annual new extra load for space cooling is 1,415 GWH. This load is partially single-phase electricity for residences, and also three-phase loads for large buildings. The single-phase portion of the total cooling is a minimum of 40% and a maximum of 70% of the total cooling load. A rough estimate is 50%, which yields an annual growth increment of 707 new GWH for single phase. The incremental cost of electricity is 40 cents per kwh for a large user new load. The incremental cost is 20 cents per kwh for a small user. Assume an average incremental cost of 30 cents per kwh, for the 707 GWH, or $300,000.00 per GWH. This annual growth increment is a new load of over 200 million dollars for single-phase space cooling in California.

If the first year market penetration were 5% of the new single-phase systems using Enablers™ with 10% savings of the electricity bill, the new load would be 10 million dollars and the first year savings would be one million dollars for the new consumers.

The market penetration could increase linearly with time, 5% more each year, up to 50% in ten years. When the market penetration is 10% in the second year, and increases 5% per year up to 50% in the tenth year, then the cumulative consumer savings would be 55 million dollars during the first ten years. Including the next ten years at 50% market, the cumulative savings would be 155 million dollars in 20 years.

In the total USA, the national electricity space cooling costs approximately 17.6 billion dollars. The annual sales of new unitary air-conditioners/heat pumps is 7.5 million units costing 5.5 billion dollars, with an average cost of $733. per unit. California loads are approximately 12% of the national loads.

Applying this ratio, California annual sales would be 0.9 million units costing 660 million dollars. At a market penetration of 5%, the new Enablers™ systems would be 45,000 units costing $33 million dollars. Assume that the factory adds an average of $10.00 per unit for additional profit and royalties. This would be a $450,000. increase in the cost to the consumer. In the first year, the savings of one million dollars is purchased by a cost of $450,000.

In ten years, the total extra initial cost to the California consumers would be 4.5 million dollars. The consumers would have saved 55 million dollars. The ten-year payback is 1,100%.

This analysis has not included the $60.00 initial cost differential savings compared to the conventional traditional single-phase air-conditioner in Paragraph 4. Project Outcomes, discussion of Table 4.12, Component Retail Prices, Model 48E.

8. Development Stage Assessment

The Stages and Gates Process of the California Energy Commission has the following Disciplines for the Stage 3 Research and Bench Scale Testing :

- Marketing The market for us is the Air Conditioner Manufacturer. The user market for the product is all new air-conditioner customers. The USA potential market is 7.5 million units costing 5.5 billion dollars annually, with a growth rate of 11.4% per year. The air-conditioning user customer needs the higher efficiency which this product provides. The air-conditioning manufacturer is making a good profit with existing low-efficiency units, and does not have a present need, either economic or regulatory, to provide these new units with higher efficiency. The reaction of our targeted customer, the

Manufacturer, is not yet known. The reaction of the residential air-conditioner user has been generally, "I wish that I had a higher efficiency unit with lower electricity costs." The high costs of a user market survey were not included in this Stage 3 project.

- Engineering / Technical The highest priority was the confirmation of technical feasibility through physical testing, and this was proved. The Model 48T had a final efficiency EER of 11.95 on single-phase power compared to the existing single-phase unit efficiency EER of only 10.7, which is an improvement of 11.7%, and a savings of 11.7% of the electricity bill. The thermodynamic tests were performed at ITS, probably the best facility in this country. The technical specifications are the same as originally proposed. The price is not considered in this report. The functional requirements were for higher efficiency, and these efficiencies have been significantly exceeded.

- Legal / Contractual All patents are held by Dr. Smith. There are no issues to be resolved. There is no commercializer agreement. See Patent References (P1) through (P7).

- Risk Assessment / Quality Plans All components are now used by the air-conditioner factories and all are underwriter approved. Reliability is high.
Similar installations (See References) have shown no failures, and the author does not know of secret factory studies of their own failures. Manufacturability is comparable to the present factory procedures. There are no hazards except possibility of failure of the hermetically-sealed enclosure and release of refrigerant. Factories already make the three-phase units and have already addressed Product safety. Environmental risk has been addressed by EPA requirements on units with refrigerants.
- Strategic There is no relationship between this project and other PIER projects.

- Production Readiness There has been no disclosure of this project results to potential commercializers. These contacts should be addressed in a future Stage 4 project.

- Public Benefits / Costs A 5% penetration of the air-conditioner market, increasing an additional 5% per each year, will yield the California consumers a ten-year payback of possibly between 400% and 1000%. This is based on year 2000 electricity costs, and there will be more expected savings resulting from increases in electricity costs after Year 2000 that can increase this amount. Anticipated extra prices and corresponding additional capital costs to the users, might be a cost of half a million dollars in the ten years. The dollar benefits might be ten times the cost. The public receives the benefits of reduced air pollution and more reliable power supply and quality, compared to the "business-as-usual" continuing sales of new low-efficiency air conditioners. Specific values for California need to be obtained.

9. Future Tasks

Stage 3, Research and Bench Scale Testing of the Stages and Gates Process of the California Energy Commission. This task will stay within the scope of the EISG Program.

This study will **modify the Model 48E compressor** which we have, to make it similar to a final design sufficient to show to a commercializer.

The compressor Model 48E is available. It is proposed that it be modified in a manner closely resembling how it would be marketed and sold as a component for an air conditioner. It presently has three terminals brought out from the hermetically-sealed motor through a Fusite bushing. It is proposed that a commercial unit (marketed by a commercializing partner) would have four electrical terminals in a four-conductor Fusite bushing. This allows for lower cost and better control.

The manufacturing modifications on the hermetic enclosure of the Model 48E compressor which Dr. Smith has can be made at Whelan Engineering Co., 1002 77-th Avenue, Oakland, CA 94621. Alfred Robertson, Foreman, Tel. 1(510)632-8890.

Dr. Smith can make the Enabler™ controls.

Thermodynamic tests will be made at Intertek Testing Services NA Inc., 4161 Arlinggate Lane, Columbus, Ohio 43228. Mike Shows, Engineering Manager of HVAC Testing, Tel. 1-(614)279-8090. Douglas Lockard, Design Engineer, Tel. 1-(614)348-2715.

Detailed Steps:

9-1. Measure Positive Temperature Coefficient (PTC) thermistor resistance in ohms for plus and minus twenty percent deviations in voltage.
9-2. Measure Electrolytic Starting Capacitor watts loss and capacitance (power-factor) for plus and minus ten percent deviations in voltage.
9-3. Test alternative augmented-starting-torque circuits using starting capacitors, and PTC or starting contactors.
9-4. Cut open a discarded 48,000 BTU/Hour Scroll Technologies compressor to determine the location of the neutral N of the Wye of the motor winding and to obtain an additional Fusite bushing.
9-5. Attach an additional Fusite bushing in the wall of the Model 48E compressor which has been tested, and bring out the motor winding terminals W4, W5, and W6. This work might be done at Whelan Engineering Co., 1002 77-th Avenue, Oakland, CA 94621. Alfred Robertson, Foreman, Tel. 1(510)632-8890.
9-6. Measure the impedances of the individual windings. Correlate the unbalanced currents at locked-rotor and at full-load with the winding impedances.
9-7. Measure the winding currents at reduced-voltage locked-rotor with designated starting capacitance values, and with modified capacitance values to create balanced currents in the unbalanced winding structure.
9-8. Measure the minimum starting capacitance values sufficient to start the motor shaft rotating, using an augmented starting torque circuit switched with a PTC thermistor.
9-9. Design a Run Capacitor bank of C1, C2, and C3 which will compensate for the unbalanced winding structure and yield full-load balanced winding currents.
9-10. Assemble a complete Enabler™ system of run capacitors and switched electrolytic starting capacitors in a single box similar to a commercial final design, for the Model 48E compressor.
9-11. Measure the EER of this new unit by thermodynamic tests of this complete unit at Intertek Testing Services NA Inc., 4161 Arlinggate Lane, Columbus, Ohio 43228. Mike Shows, Engineering Manager of HVAC Testing, Tel. 1-(614)279-8090. Douglas Lockard, Design Engineer, Tel. 1-(614)348-2715. Winding and Line currents will be measured and unbalances calculated, and

winding and line voltages will be measured and unbalances calculated, as well as the ASHRAE and ARI thermodynamics and input watts.
9-12. Particular attention will be given to the tested-winding current balance, and the change in EER due to this improved Enabler™ circuit.

Smallest available compressor with three-phase motor.

We need to know the EER savings for the range of sizes made and used in the USA. The smallest size is 12,000 BTU/Hour. In this original EISG grant #99-04, in the narrative details of the project, it stated**:** "The sizes of importance will be 18,000 BTU/Hour, 36,000 BTU/Hour, 41,500 BTU/Hour, and 60,000 BTU/Hour. This range is from 1.5 tons to 5 tons. Depending upon the grant funds, more than one size or more than one manufacturer might be considered."
At the completion of this present grant, we have tested two sizes, 42,000 BTU/Hour and 48,000 BTU/Hour, from only one manufacturer. To understand the market and the engineering for other sizes, we should test the smallest unit available.

We should not extrapolate to smaller sizes based on the present test results. The smallest commercial 3-phase unit will be called Model 12T, 12,000 BTU/Hour. This small unit will be acquired and tested with an Enabler™ control similar in design to the SemiHex™ Model 48E.

Available are:
Tecumseh, Model AHA2445AXF, 1.0 HP, 1 KW, 12,000 BTU/Hour, 3-phase, 230 volts, R12 refrigerant;
Tecumseh, Model AWG5515EXT, 1.25 HP, 1.2 KW, 15,000 BTU/Hour, 3-phase, 230 volts, R22 refrigerant;
Copeland, Model F3AM-A105-TFC-001, 1.0 HP, 1 KW, 12,000 BTU/Hour, 3-phase, 230 volts, R22 refrigerant;
Copeland, Model F3AD-A151-TFC-001, 1.5 HP, 1.5 KW, 18,000 BTU/Hour, 3-phase, 230 volts, R22 refrigerant.

The compressor system can be made with a four-terminal Fusite bushing, an Enabler™ circuit balancing the winding currents, and with a small starting-torque augmentation using electrolytic starting capacitors. The justification for additional technical changes is that an Enabler™ circuit can be made weighing less and costing less, that a four-terminal Fusite bushing can replace the three-terminal bushing, providing flexibility and simplifying the control circuit, and that a minimum-cost starting-torque augmentation circuit can be studied and a minimum-cost circuit developed, and all of the above tested.

The field experiments for the above are ARI and ASHRAE standard condition tests at ITS. These will duplicate the tests previously made, and would satisfy the criteria of this duplication.

Detailed Steps for Model 12T:

9-13. Buy a good three-phase Model 12T, and acquire a discarded similar model. Buy a good Model 12S, with the same compressor, but with a single-phase motor winding.

9-14. Get factory specifications for the Model 12T, including full-load current, power-factor, efficiency, locked-rotor current and power-factor.
9-15. Design the preliminary run-capacitor bank and the starting capacitor circuit.
9-16. Cut open the discarded 12,000 BTU/Hour Compressor to determine the location of the neutral N of the Wye of the motor winding and to obtain an additional Fusite bushing.
9-17. Attach the additional Fusite bushing in the wall of the good Model 12T compressor which will be tested, and bring out the motor winding terminals W4, W5, and W6. This work might be done at Whelan Engineering Co., 1002 77-**th** Avenue, Oakland, CA 94621. Alfred Robertson, Foreman, Tel. 1(510)632-8890.
9-18. Measure the impedances of the individual windings. Correlate the unbalanced currents at locked-rotor and at full-load with the winding impedances.
9-19. Measure the winding currents at reduced-voltage locked-rotor with designated starting capacitance values, and with modified capacitance values to create balanced currents in the winding structure if unbalanced.
9-20. Measure the minimum starting capacitance values sufficient to start the motor shaft rotating, using an augmented starting torque circuit switched with a PTC thermistor.
9-21. Design a Run Capacitor bank of C1, C2, and C3 which will compensate for an unbalanced winding structure and yield full-load balanced winding currents.
9-22. Assemble a complete Enabler™ system of run capacitors and switched electrolytic starting capacitors in a single box similar to a commercial final design.
9-23. Measure the EER of this new unit by thermodynamic tests of this complete unit at Intertek Testing Services NA Inc., 4161 Arlinggate Lane, Columbus, Ohio 43228. Mike Shows, Engineering Manager of HVAC Testing, Tel. 1-(614)279-8090. Douglas Lockard, Design Engineer, Tel. 1-(614)348-2715.
9-24. Winding and Line currents will be measured and unbalances calculated, and winding and line voltages will be measured and unbalances calculated, as well as the ASHRAE and ARI thermodynamics and input watts.
9-25. Draw conclusions regarding the changes in EER improvement as a function of compressor size.

Stage 4, Technology Development and Field Experiments, and Gate 4, Product Development Initiation of the EISG Stages and Gates Process.

9-26. Refine estimates of annual USA and California Electrical Cooling Loads, and the annual growth in terms of product units, BTUs, Electrical MWH, and Electrical costs in dollars.
9-27. Subdivide the above information into single-phase loads and three-phase loads.
9-28. Obtain OEM costs for large production runs of the compressors and the starting and run capacitors.

Material costs for manufacturing single-phase and three-phase motors are nearly identical. Manufacturing costs however are today higher for the three-phase motors due to differences in production scale. Single-phase motor production is about twice as large as three-phase motor production in the 1.5-HP to 5-HP range, and this economy of scale reduces the costs of single-phase motor manufacturing by approximately 20% below the costs of three-phase motors. With significant increases in the three-phase production, and corresponding decreases in the single-phase production, this cost differential will be reversed. Three-phase motors will eventually become 20% less in cost, and single-phase motors will eventually become 20% more expensive, with a substantial relative cost benefit to the new three-phase motors.

9-29. Calculate possible financial benefits to each of the major air-conditioner manufacturers.

Manufacturer		1997 Market Share %	Manufacturer	1997 Market Share %
(a)	Carrier	21 %	(e) International C.P.	10%
(b)	Goodman	19 %	(f) Lennox	9%
(c)	Rheem	13%	(g) York	8%
(d)	Trane	12%	(h) Nordyne	5%

9-30. Prepare a presentation to the Vice-President for Marketing of each company.

9-31. Investigate suitable locations for permanent installations of the two compressors which we will have, Model 48E and Model 12E. These could be schools, community centers, hospitals, research stations, or institutional offices. These installations should be open to field trips and classes in appropriate technology and consumer product efficiencies.

9-32. An example of a useful collaboration is the Smith and Sun successful 30 KW (40 HP) installation near Twin Falls, Idaho. This was created by the cooperation of two factories, Idaho Power Company, a local electrician, a consumer, a government agency, and Dr. Smith. Within a few months, the entire system was designed, built, tested, and demonstrated to 60 engineers and farmers. It has been operating for several years.

9-33. Ask the associated power company to install recording monitoring equipment for amperes, watts, watt-hours, and temperatures.

9-34. To make each system, a single-phase unit would be purchased minus the compressor, and we would install our own compressor with its Enabler control. A commercializer might be interested in cooperating by providing the entire system at cost or free.

9-35. The technology transfer plan will follow from the data obtained in the actual installations. 9-36. Our marketing strategy is to persuade a commercializer to be interested. His marketing system already exists. We will cooperate, not compete.

9-37. Dr. Smith will approach a candidate for commercializing after the completion of these production prototype tests. It is optimistic to obtain a commercializer's binding commitment to proceed unless these tests are encouraging and the California Energy Commission wishes to proceed in that direction. We wish to encourage them to market complete lines of single-phase air conditioners of all sizes, utilizing their three-phase compressor systems with Enabler™ controls in nearly all of their single-phase systems.

9-38. Regarding the CEC Appliance Efficiency Regulations for Room Air Conditioners and Central Air Conditioners, the values on pages 25 and 29 will be studied with respect to the achievable much higher values. These values of EER are in the range of 7.7 up to 9.9. All of these might be raised by ten percent. The CEC could schedule a conference of these manufacturers to discuss the appropriate new values for each appliance for connection to residential, rural, small commercial and motel single-phase power with Enabler™ controls.

9-39. It is suggested that the CEC internally discuss incentives and credits to consumers who decide to purchase high-efficiency air conditioners with efficiencies greater than specified target values.
9-40. The method herein is applicable to increasing the efficiencies of freezers and refrigerators. Researchers in these fields should be contacted to exchange information and to evaluate the contribution which Enablers^{TM} can make to freezers and refrigerators. This method can be used for large air conditioners and chillers with non-hermetic external high-efficiency three-phase motors on single-phase supplies.
9-41. This method herein is applicable to increasing the efficiencies of ventilation fans, furnace fans, air-conditioning fans, sump pumps, air compressors for tools, and irrigation pumps. Researchers in these fields should be contacted and requested to augment their activities by using these methods.

References

P1. "Three-Phase Induction Motor with Single-Phase Power Supply", U.S. Patent No. 4,792,740, issued 20 December 1988 to O. J. M. Smith.
P2. "Three-Phase Motor Control", U.S. Patent No. 5,300,870, issued 5 April 1994, to O. J. M. Smith.
P3. "Three-Phase Motor Operated From A Single-Phase Power Supply and Phase Converter", U.S. Patent No. 5,545,965, issued 13 August 1996, to O. J. M. Smith.
P4. "Motor Starter", U.S. Patent No. 6,025,693, issued 15 February 2000, to O. J. M. Smith.
P5. "Single-Phase Motor Starters", U.S. Patent No. 6,049,188, issued April 11, 2000, to O. J. M. Smith.
P6. "Three-Phase Motor Control", People's Republic of China Patent No. 95105163.6, Certificate No. 65335, issued December 8, 2000. In force April 18, 1995 to April 18, 2015. Inventor O. J. M. Smith.
P7. "Three-Phase Motor Control", Brazilian Patent No. PI9304033-4; Granted December 26, 2000; Issue Published April 17, 2001; Expiration October 19, 2013. Inventor O. J. M. Smith.
P8. "Master Three-Phase Induction Motor with Satellite Three-Phase Motors Driven by Single-Phase Supply"; U.S. Patent granted, not yet issued, to O. J. M. Smith.

1. ANSI/ARI Standard 500-90, *Variable Capacity Positive Displacement Refrigerant Compressors and Compressor Units for Air-Conditioning and Heat Pump Applications, 1990, American Standards Institute / Air-Conditioning & Refrigeration Institute,* 11 West 42-nd Street, New York, NY 10036, USA.
2. ASHRAE Standard 23-1993, *Methods of Testing for Rating Positive Displacement Refrigerant Compressors and Condensing Units*, 1993.
3. ASRE ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1791 Tullie Circle N.E., Atlanta, GA 30329, USA.
4. ARI. Air-Conditioning and Refrigeration Institute, 4301 North Fairfax Drive, Suite 425, Arlington, VA 22203, USA. ARI Standard 540-1999.

5. Smith, O.J.M., "LARGE LOW-COST SINGLE-PHASE SEMI-HEX™ MOTORS", Paper No. MB2-5, 1997 IEEE International Electric Machines and Drives Conference, May 18-21, 1997, Milwaukee, Wisconsin, IEEE Catalog No. 97TH8282, pages MB2-5.1 to MB2-5.3.
6. Smith, O.J.M., "High-Efficiency Single-Phase SEMI-HEX™ Motors", Electric Machines and Power Systems, Vol. 26, No. 6, June 1998, pp. 573-584.
7. Smith, O.J.M., "LARGE LOW-COST SINGLE-PHASE SEMI-HEX™ MOTORS", IEEE Transactions on Energy Conversion, Vol. 14, No. 4, December 1999, pp 1353-1358. Abstract in IEEE Power Engineering Review, Vol. 18, No.5, May 1998, page 53.
8. O.J.M. Smith and Clinton C. Shock, "Circuitry Innovation For Three-Phase Motor Operation on Single-Phase Power", Applied Engineering in Agriculture, ASAE, Vol. 15, No. 5, September/October 1999, pp 577-582.
9. O.J.M. Smith, "Single-Phase Motor Revolution", Banquet Address, Proceedings of 31-st North American Power Symposium 1999, California Polytechnic State University, San Luis Obispo, California, October 11, 1999, pp 313-326.
10. O.J.M. Smith, "Large Low-Cost Single-Phase Semi-Hex™ Motors", IEEE Transactions on Energy Conversion, Vol. 14, No. 4, December 1999, pp 1353-1358. Abstract in IEEE Power Engineering Review, Vol. 18, No. 5, May 1998, page 53.
11. Tze-Fun Chan and L.L. Lai, "Steady-State Analysis of a Three-Phase Induction Motor with the Smith Connection", IEEE Power Engr. Review, Vol. 20, No. 10, October 2000, pp 45-46.
12. O.J.M. Smith, "Discussion of the Smith Connection by Chan and Lai", IEEE Power Engineering Review, Vol. 21, No. 6, June 2001, pp 65-67.
13. Ed Campaniello and Jeff Cole, "Phase-Able Enabler Business Plan", Energy and Resources Group, 310 Barrows Hall, and Haas School of Business, Haas School of Business #1930, University of California, Berkeley CA 94720. May 1999.
14. Baldor Catalog 502, page A-4, Figure 2. Baldor Electric Company, P.O. Box 2400, Fort Smith, Arkansas 72902. Tel. 1-(501)646-4711.
15. Stages and Gates Process, California Energy Commission, The Resource Agency, State of California, 1516 Ninth Street, Sacramento, CA 95814 -5512. 1(916)654-4397.
16. Appliance Efficiency Regulations for [Room Air Conditioners, Central Air Conditioners] California Energy Commission, P400-92-029, September 1992, pages 25 and 29.

Glossary

ARI	Air-Conditioning and Refrigeration Institute
ASRE	ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers.
BTU	British Thermal Units
CS	Starting Electrolytic Capacitor.
C1	Metallized Polypropylene Run Capacitor.
EER	ENERGY EFFICIENCY RATIO as BTU/(WATT-HOUR)
Enabler™	See http://www.home.earthlink.net/~ojmsmith
FLA	Full-Load Line Amperes.

FLPF	Full-Load Power-Factor of Watts / (Volt-Amperes)
GWH	GigaWattHour = 10^{12} Watt-Hours
HP	Horsepower
ITS	Intertek Testing Services
KW	KiloWatt = 1000 watts.
L	Power-Line Terminal.
LRA	Locked-Rotor Line Amperes
LRPF	Locked-Rotor Power-Factor of Watts / (Volt-Amperes)
MFD	Microfarads
MW	MegaWatts = 1,000,000 watts.
PF	Power-Factor
PQ	Power Quality
Q	Compressor output in BTU / HOUR.
RATIO	Ratio of Starting Current LRA to Full-Load Current FLA.
RATIO	(LRA) / (FLA).
w	watts
Wn	Winding terminal n.
Φ^{o}	Phase Angle of Current with respect to Voltage.
$FL\Phi^{o}$	Phase Angle of Full-Load Current with respect to Line-to-Neutral Voltage.
$LR\Phi^{o}$	Phase Angle of Locked-Rotor Current with respect to Line-to-Neutral Voltage.
42E	Model 42,000 BTU/HOUR with Enabler driving the Three-Phase winding.
48E	Model 48,000 BTU/HOUR with Enabler driving the Three-Phase winding.
42S	Model 42,000 BTU/HOUR with Single-Phase winding.
48S	Model 48,000 BTU/HOUR with Single-Phase winding.
42T	Model 42,000 BTU/HOUR with Three-Phase winding.
48T	Model 48,000 BTU/HOUR with Three-Phase winding.

APPENDICES

APPENDIX I. Test specifications:

ARI Standard 540-1999.

Ambient 95^{o} F, Return Gas 65^{o} F, Compressor Suction 65^{o} F, Liquid 115^{o} F.

ASHRAE Standard 23-1993,

Ambient 95^{o} F, Return Gas 95^{o} F, Compressor Suction 65^{o} F, Liquid 115^{o} F.

APPENDIX II. Web Site for Dr. Otto J. M. Smith:

http://www.home.earthlink.net/~ojmsmith

TABLES

TABLE 4.1

EER SUMMARY MEASURES EFFICIENCY

MODEL	DIRECT THREE-PHASE	ENABLER™ FROM SINGLE-PHASE POWER	SINGLE-PHASE MOTOR ON SAME COMPRESSOR
48T	12.436		
48E		11.950	
48S			10.694
42T	10.816		
42E		11.294	
42S			10.865
AVERAGE	11.626	11.622	10.779

WITH THE 48T COMPRESSOR, THE EER MODEL 48E OF 11.95 WITH THE THREE-PHASE MOTOR AND ENABLER™ IS 11.74% HIGHER THAN WITH A SINGLE-PHASE MOTOR ON THE SAME COMPRESSOR, MODEL 48S.

WITH THE SMALLER 42T COMPRESSOR, THE EER OF MODEL 42E OF 11.294 WITH THE THREE-PHASE MOTOR AND ENABLER™ IS 3.95% HIGHER THAN WITH A SINGLE-PHASE MOTOR ON THE SAME COMPRESSOR, MODEL 42S.

THE AVERAGE EER OF BOTH ENABLERS™ IS 11.6, WHICH IS 7.8% MORE THAN THE AVERAGE EER OF 10.78 OF BOTH SINGLE-PHASE UNITS.

TABLE 4.2

SYSTEM TESTS

TABLE 4.2A MODEL 48 THREE-PHASE TEST DETAILS.

TEST	WATTS* INPUT TO COMPRESSOR	Q BTU/HOUR	EER BTU/(WATT-HOUR)
DIRECT CONNECTIONS TO THREE-PHASE POWER, MODEL 48T:			
ARI	3,870.82	47,857.09	12.363
ASHRAE-T	3,871.33	48,423.64	12.508
AVERAGE	3,871.08	48,140.37	12.436
ENABLER™ WINDING CONNECTIONS TO SINGLE-PHASE POWER, MODEL 48E:			
ARI	4,074.45	48,143.78	11.816
ASHRAE-T	4,029.60	48,689.86	12.083
AVERAGE	4,052.02	48,416.82	11.950

MODEL 48 SINGLE-PHASE TEST DETAILS

TEST	WATTS* INPUT TO COMPRESSOR	Q BTU/HOUR	EER BTU/(WATT-HOUR)
DIRECT CONNECTIONS TO SINGLE-PHASE POWER, MODEL 48S:			
ARI	4,333.514	46,293.93	10.6828
ASHRAE-T	4,413.900	47,249.57	10.7047
AVERAGE	4,373.707	46,771.75	10.6938

TABLE 4.2B MODEL 42T TEST DETAILS.

TEST	WATTS* INPUT TO COMPRESSOR	Q BTU/HOUR	EER BTU/(WATT-HOUR)
DIRECT CONNECTIONS TO THREE-PHASE POWER, MODEL 42T:			
ARI	3,876.05	41,754.64	10.772
ASHRAE-T	3,858.95	41,904.81	10.861
AVERAGE	3,867.50	41,829.73	10.816
ENABLER™ WINDING CONNECTIONS TO SINGLE-PHASE POWER, MODEL 42E:			
ARI	3,672.35	42,020.86	11.442
ASHRAE-T	3,767.14	42,000.38	11.149
AVERAGE	3,719.75	42,010.62	11.294
DIRECT CONNECTIONS TO SINGLE-PHASE POWER, MODEL 42S:			
ARI	3,835.408.	41,304.23	10.7692
ASHRAE-T	3,824.715.	41,918.47	10.9599
AVERAGE	3,830.062	41,611.35	10.8645

- WATTS CALIBRATED TO Yokogawa WT 110, Asset E337. Control Room Wattmeter Asset E358 calibration constant $K_{(358)}$ = 0.9726 for 3-phase wattage reading of 3,720 watts, and $K_{(358)}$ = 0.9348 for 3-phase wattage reading of 4,050 watts. Note: Q is measured by the primary calorimeter method.

TABLE 4.3
UNBALANCED CURRENTS IN WINDINGS

DIRECT CONNECTION TO THREE-PHASE POWER, THREE WINDINGS.

MODEL	VOLTAGE	CURRENT	UNBALANCE %	
	AVERAGE	AVE. AMPS.	VOLTAGE	CURRENT
48T	230.04	13.41	0.397 %	7.365 %
42T	230.06	12.46	0.254 %	13.775 %

ENABLER™ CONNECTION TO SINGLE-PHASE POWER, THREE WINDINGS.

MODEL	VOLTAGE	CURRENT	UNBALANCE %		UNBALANCE REDUCED
	AVERAGE	AVE. AMPS.	VOLTAGE	CURRENT	BY ENABLER, TO FACTOR
48E	232.462	13.428	0.995 %	1.050 %	0.143
42E	232.717	12.024	1.758 %	3.216 %	0.234

Note: The large current unbalance on Model 42T with a low voltage unbalance might be due to a construction winding error.

TABLE 4.4
FULL-LOAD THREE-PHASE MEASUREMENTS
DIRECT TESTS TO BE COMPARED TO FACTORY SPECIFICATIONS

MODEL	Q BTU/HOUR	CURRENT AMPERES	WATTS	% POWER-FACTOR	LAG ANGLE Φ, DEGREES	EER
48T	48,140.37	13.409	3,871.08	72.45	43.571°	12.44
42T	41,829.72	12.456	3,867.50	77.92	38.809°	10.82

TABLE 4.5
FULL-LOAD THREE-PHASE FACTORY OLD PREVIOUS EXPECTED VALUES

MODEL	Q BTU/HOUR	CURRENT AMPERES	WATTS	POWER-FACTOR %	LAG ANGLE Φ, DEGREES
48T	46,770	13.6	4,070	75.1	41.32°
42T	41,233	11.6	3,812.	82.5	34.42°

TABLE 4.6
FULL-LOAD ENABLER™ WINDING MEASUREMENTS

MODEL	Q BTU/HOUR	WINDING AMPS. AVE.	WATTS	VOLTS AVE.	% POWER-FACTOR	LAG ANGLE Φ, DEGREES	EER
48E	48,416.82	13.428	4,052.02	232.46	74.947	41.456°	11.95
42E	42,010.62	12.024	3,719.75	232.72	76.749	39.871°	11.29

TABLE 4.7

FULL-LOAD ENABLER™ SINGLE-PHASE INPUT MEASUREMENTS

MODEL	Q BTU/HOUR	LINE AMPERES	WATTS	VOLTS LINE	POWER-FACTOR % **LEADING**	**LEAD** ANGLE Φ, DEGREES
48E	48,416.82	19.390	4,052.0	230.15	90.799	24.771°
42E	42,010.62	18.266	3,719.7	230.71	88.267	28.034°

TABLE 4.8

FULL-LOAD ENABLER™ BALANCED WINDING VALUES FOR 230 VOLTS.

MODEL	Q BTU/HOUR	WINDING AMPS. AVE.	WATTS	VOLTS	POWER-FACTOR %	LAG ANGLE Φ, DEGREES
48E	48,416.82	13.538	4,053.77	230.0	75.165	41.266°
42E	42,010.62	12.133	3,721.57	230.0	76.995	39.646°

TABLE 4.9

CAPACITOR MFD VALUES FOR SEMI-HEX™ ENABLER™

4-TERMINAL CONNECTION TO 230.0 VOLTS

MODEL	MFD			WINDING	LINE	LINE % **LEADING**
	C1	C2	C3	AMPERES	AMPERES	POWER-FACTOR
48E	86.8	173.7	61.0	13.538	18.29	96.36
42E	84.3	168.6	46.9	12.133	17.02	95.07

For factory construction, from Table 4.9, round off the capacitor values to the nearest conveniently available standard size. Smaller than design values will make the winding current balance occur at slightly less than full load, which is acceptable.

TABLE 4.10

FULL-LOAD COMPRESSOR OUTPUTS

MODEL	Q BTU/HOUR		IMPROVEMENT IN Q DUE TO
	THREE-PHASE INPUT	ENABLER™ INPUT	ENABLER™ INPUT
48T, 48E	48,140.37	48,416.82	0.574 %
42T, 42E	41,829.73	42,010.62	0.433 %

TABLE 4.11
COMPRESSOR COMPARISONS

MODEL	Q, BTU/HOUR	
48T	48,140.37	
48E	48,416.82	
48A = AVERAGE (48T,48E)	48,278.6	48,278.6
48S	46,771.75	46,771.75
RATIO (48S/48A)		0.9688
ASSUMED SPEED RATIO		0.9843

TABLE 4.12
COMPONENT RETAIL PRICES, MODEL 48E:

COMPRESSOR CARLYLE SRY482AC, $ 300.00

BTU/HOUR	=	48,420
KW	=	4.05
EER	=	11.95

ENABLER™ RUN CAPACITOR RETAIL COSTS

C1	$ 29.
C2	67.
C3	24.
TOTAL	120.

START COMPONENTS AND CS3 CAPACITOR,
$ 8.

SAVINGS IN LARGE PRODUCTION RUN OF COMPRESSOR,
20% OF $ 300. = $ 60. EACH.

SAVINGS IN LARGE PURCHASES OF CAPACITORS,
50% OF $128. = $ 64.

EXPECTED NEW RETAIL PRICE OF COMPRESSOR, $ 240.

ENABLER™ NEW RETAIL PRICE 64.

NEW ENABLER™ 48E SYSTEM RETAIL PRICE, $ 304.

NOTE: CAPACITOR COSTS CAN ALSO POSSIBLY BE REDUCED
BY CORNELL-DUBLIER PACKAGING IN A SINGLE CAN.

CONVENTIONAL SINGLE-PHASE SYSTEM PRICES

COMPRESSOR	$ 269.00
RUN CAPACITOR	23.71

FOUR PTC	7.80
TOTAL	300.51

FIGURES

612 Euclid Avenue, Berkeley, CA 94708-1332, USA
Tel. 1(510)525-9126.
<ojmsmith@earthlink.net>

http://www.home.earthlink.net/~ojmsmith

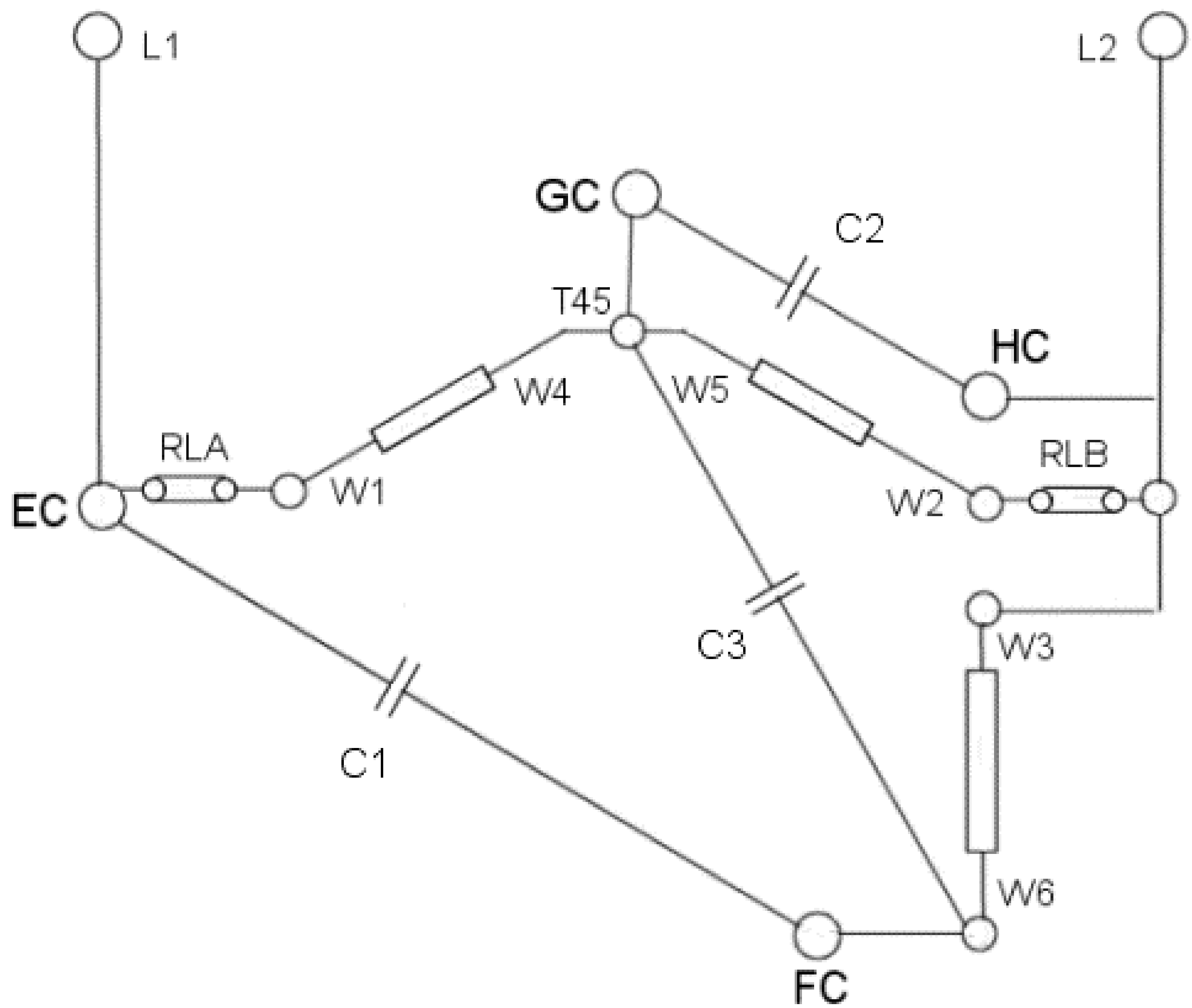


FIGURE 4.1
SEMI-HEX™ ENABLER™ WINDING CONNECTION
FOR THREE-WINDING MOTOR

Reversing Link RL connections are shown for Voltage Phase Sequence W3-W2-W1.

For Voltage Phase Sequence of W1-W2-W3**:**
Connect Reversing Link RLA between W1 and L2.
Connect Reversing Link RLB between W2 and L1.

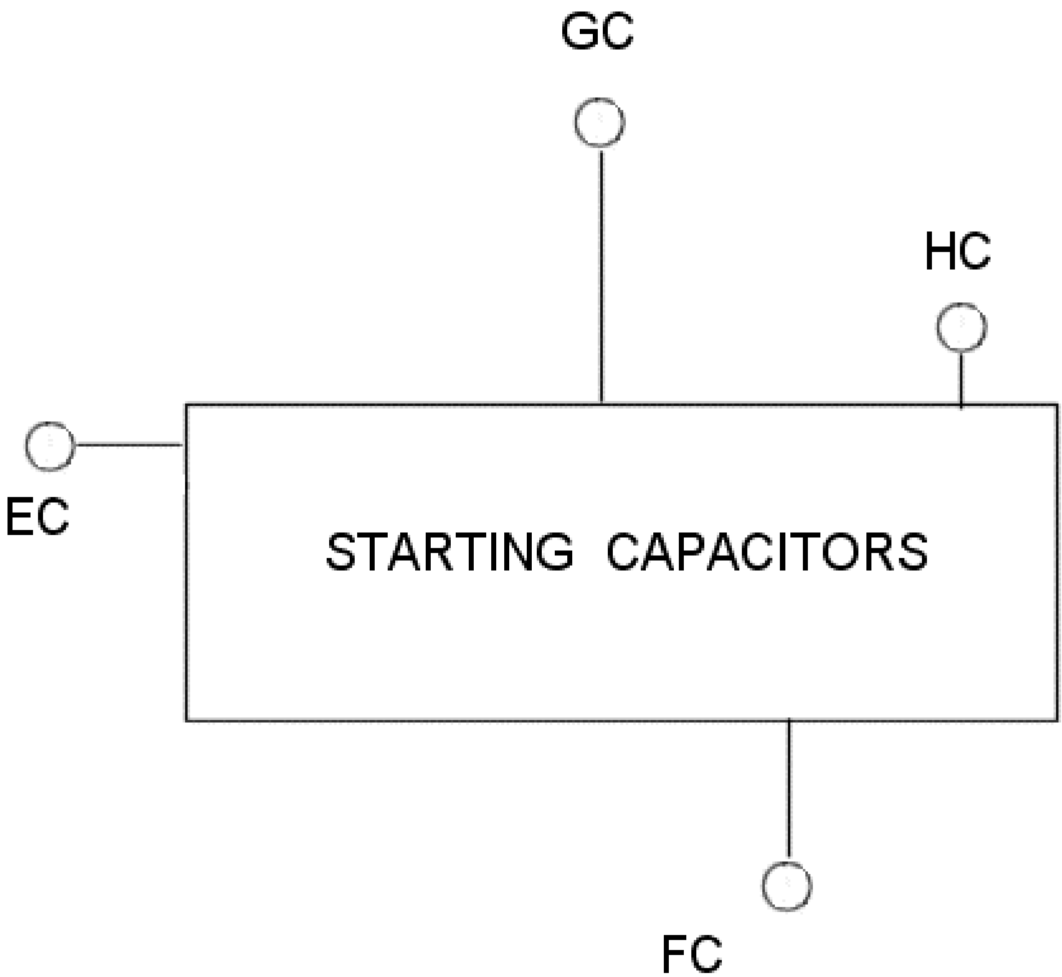
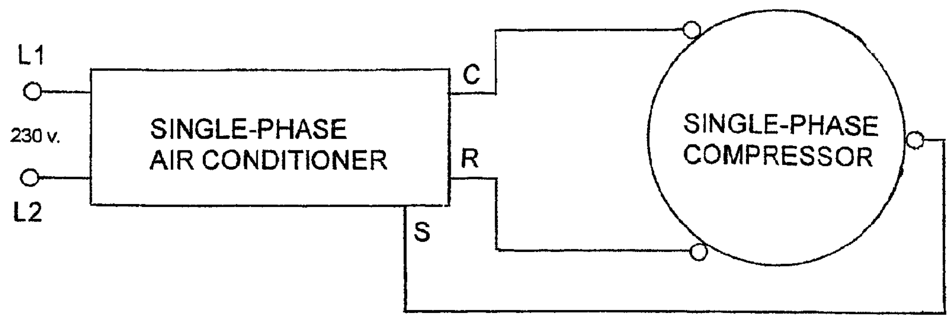
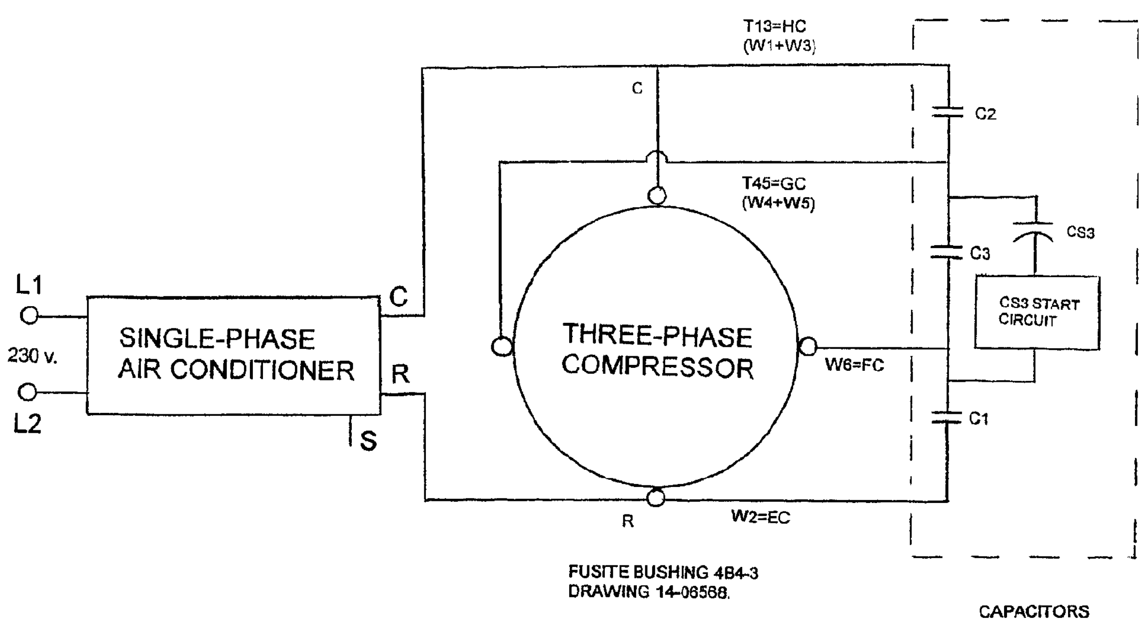


FIGURE 4.2

PROPRIETARY CIRCUIT FOR AUGMENTED STARTING TORQUE

612 Euclid Avenue,
Berkeley, CA 94708-1332, USA
Tel. 1(510)525-9126.
http://www.home.earthlink.net/~ojmsmith

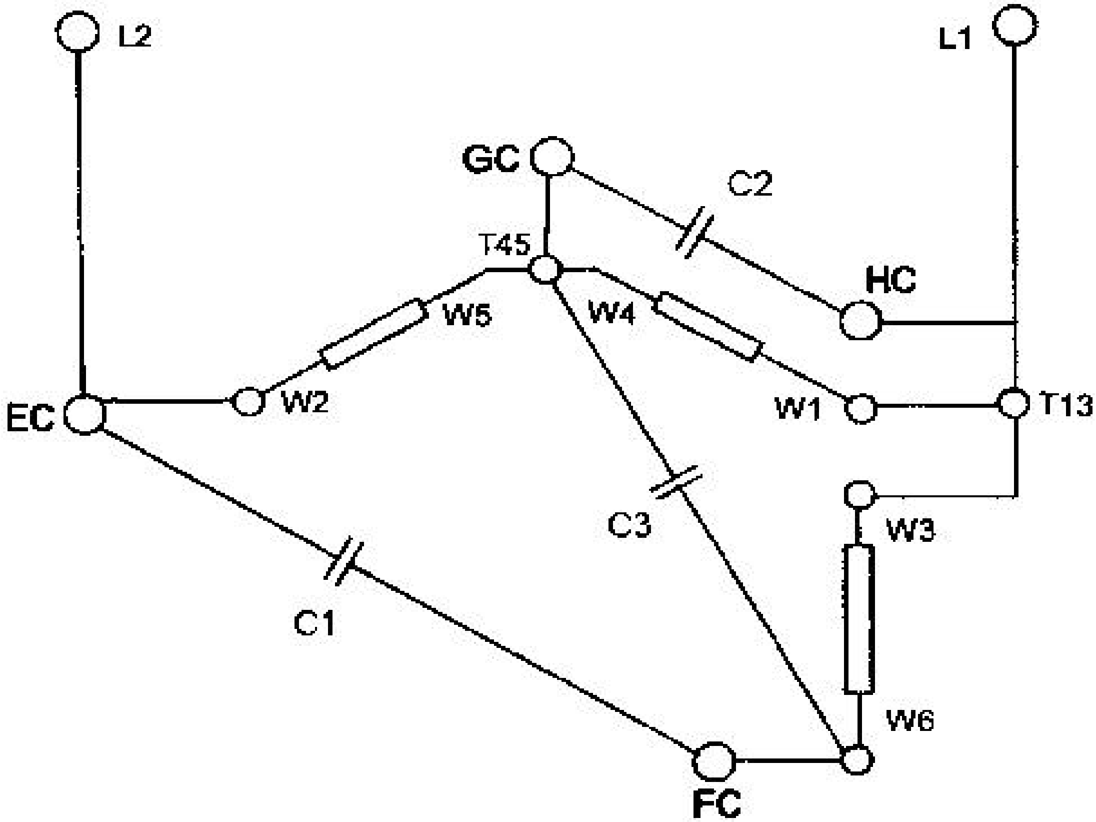




THREE-PHASE COMPRESSOR REPLACING SINGLE-PHASE COMPRESSOR

FIGURE 4.3

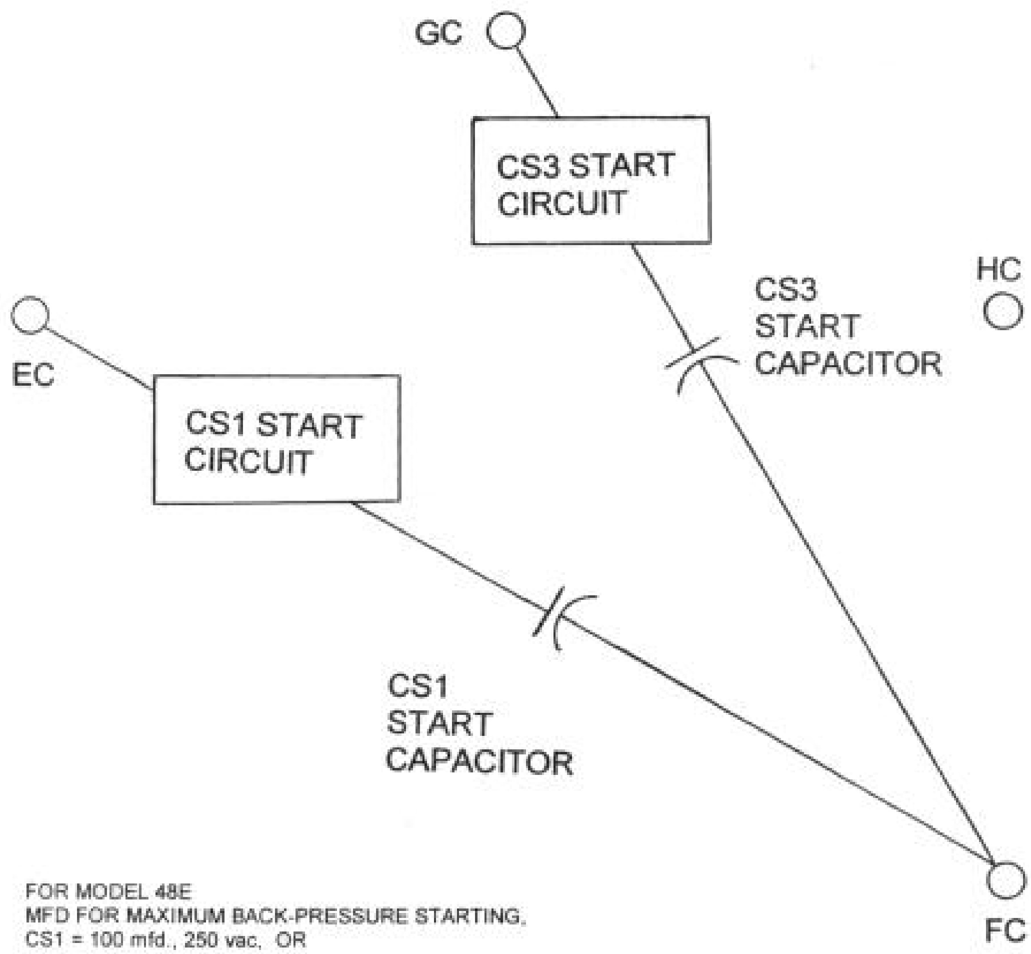
Dr. Otto J. M. Smith
612 Euclid Ave
Berkeley, CA 94708-1332



SEMI-HEX™ ENABLER™ WINDING CONNECTION
FOR THREE-WINDING MOTOR

FOR MODEL 48E
C1 = 87 MFD
C2 = 174 MFD
C3 = 61 MFD

FIGURE 4.4

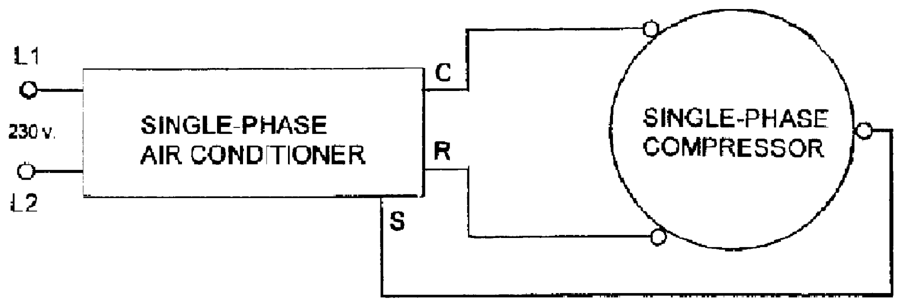


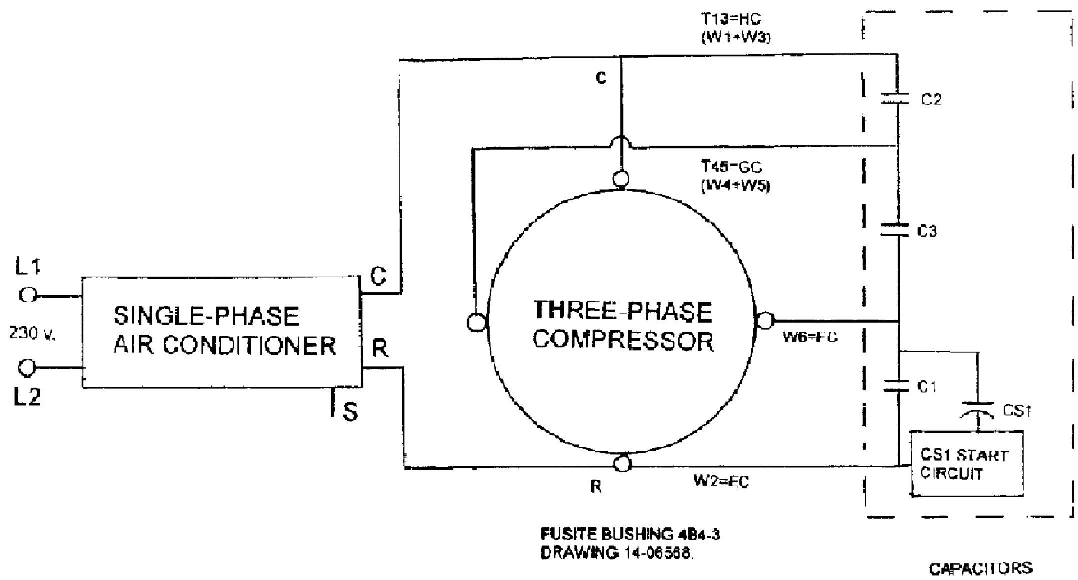
FOR MODEL 48E
MFD FOR MAXIMUM BACK-PRESSURE STARTING,
CS1 = 100 mfd., 250 vac, OR
CS3 = 75 mfd., 250 vac.

PROPRIETARY CIRCUITS FOR AUGMENTED STARTING TORQUE

FIGURE 4.5

Dr. Otto J. M. Smith
612 Euclid Ave
Berkeley, CA 94708-1332





THREE-PHASE COMPRESSOR REPLACING SINGLE-PHASE COMPRESSOR

FIGURE 4.6

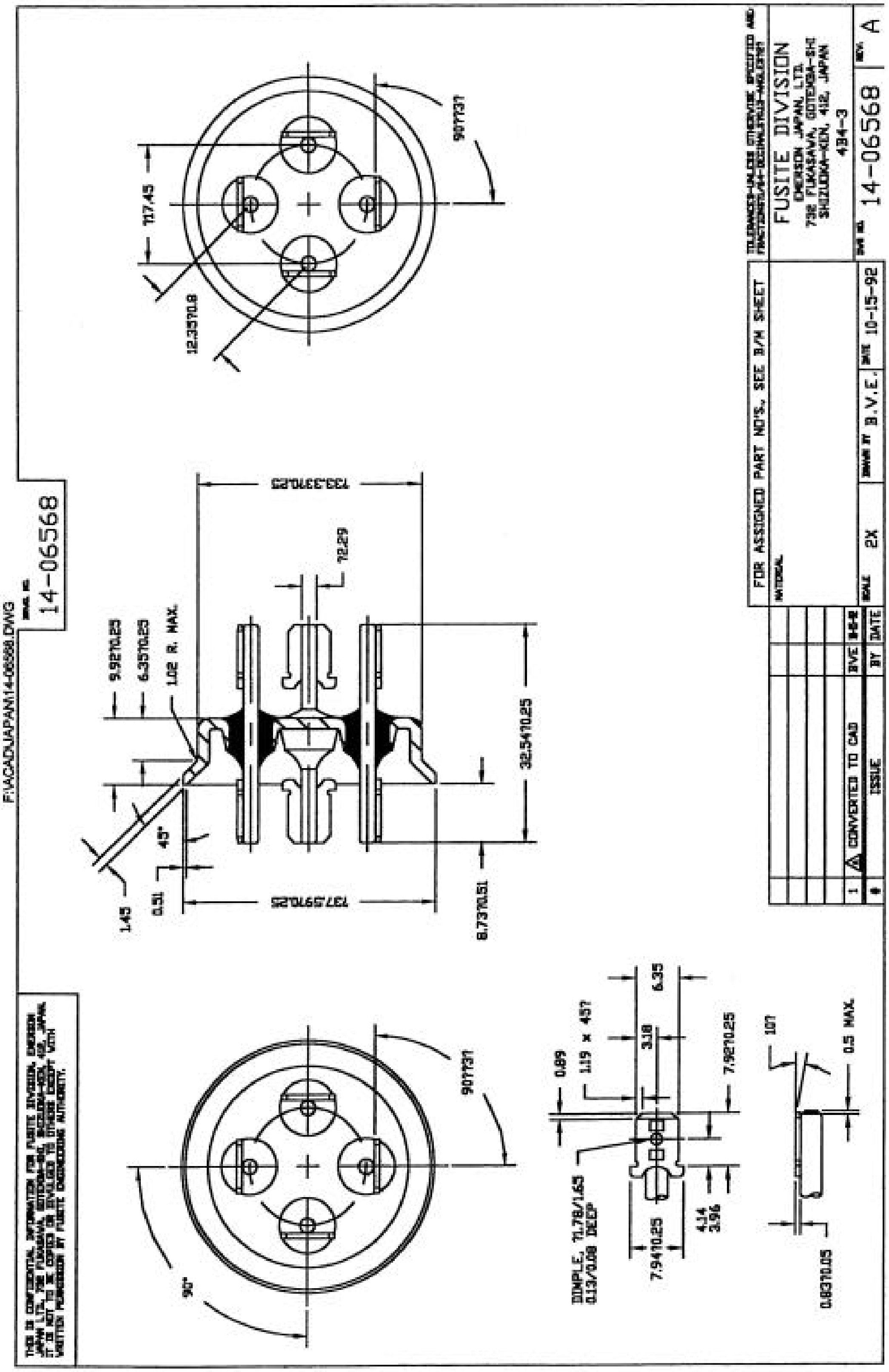

F:\ACAD\JAPAN\14-06568.DWG
14-06568
FOR ASSIGNED PART NO'S., SEE B/M SHEET
FUSITE DIVISION
EMERSON JAPAN, LTD.
434-3
14-06568
A
CONVERTED TO CAD
ISSUE
BY
DATE
2X
B.V.E.
10-15-92
45°
90°
0.5 MAX.
1.02 R. MAX.

FIGURE 4.7